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Environmental Impacts of Mineral Depletion, Population Density, Energy Productivity and Economic Growth in E-7 Countries: Fresh Evidence from MMQR Analysis

Impactos ambientales del agotamiento de recursos minerales, la densidad poblacional, la productividad energética y el crecimiento económico en los países E-7: nuevas evidencias desde el análisis MMQR

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Abstract

This study explores how mineral resource depletion, population density, energy productivity, and economic development affect environmental degradation in Emerging 7 (E-7) countries—Brazil, Indonesia, China, Mexico, India, Türkiye, and Russia. The Method of Moments Quantile Regression (MMQR) was used in the research, which included data from 1992 to 2021. Additionally, the research used the Driscoll-Kraay estimator, Fully Modified Ordinary Least Squares (FMOLS), and Dynamic Ordinary Least Squares (DOLS). The Method of Moments Quantile Regression (MMQR) results show that carbon emissions increase with mineral depletion across all quantiles. However, energy productivity lowers carbon emissions across all quantiles, but economic growth and population density raise these emissions. All these results are all statistically significant. These findings are also supported by the Driscoll-Kraay estimator, Fully Modified Ordinary Least Squares (FMOLS), and Dynamic Ordinary Least Squares (DOLS) results. The research highlights the need for resource-efficient policies and sustainable consumption, providing novel insights into ecological challenges facing emerging economies.

Keywords: Mineral depletion, Population density, Environmental deterioration, Energy productivity, E-7 countries, MMQR.

Resumen

Este estudio analiza cómo el agotamiento de los recursos minerales, la densidad de población, la productividad energética y el desarrollo económico influyen en la degradación ambiental en los países del grupo Emerging 7 (E-7): Brasil, Indonesia, China, México, India, Turquía y Rusia. En la investigación se utilizó el Método de Regresión Cuantílica por Momentos (MMQR), que incluyó datos del periodo comprendido entre 1992 y 2021. Además, en el estudio se utilizaron el estimador de Driscoll-Kraay, el método de Mínimos Cuadrados Ordinarios Totalmente Modificado (FMOLS) y el método de Mínimos Cuadrados Ordinarios Dinámicos (DOLS). Los resultados del Método de Regresión Cuantílica por Momentos (MMQR) muestran que las emisiones de carbono aumentan a medida que se agotan los recursos minerales en todos los cuantiles. Sin embargo, la productividad energética reduce las emisiones de carbono en todos los cuantiles, mientras que el crecimiento económico y la densidad de población las incrementan. Todos estos resultados son estadísticamente significativos. Estos hallazgos también están respaldados por los resultados obtenidos con el estimador de Driscoll-Kraay, el método de Mínimos Cuadrados Ordinarios Totalmente Modificado (FMOLS) y el método de Mínimos Cuadrados Ordinarios Dinámicos (DOLS). El estudio pone de relieve la necesidad de adoptar políticas que promuevan el uso eficiente de los recursos y el consumo sostenible, y ofrece nuevas perspectivas sobre los retos ecológicos a los que se enfrentan las economías emergentes.

Palabras clave: Agotamiento de recursos minerales, Densidad poblacional, Deterioro ambiental, Productividad Energética, Países E-7, MMQR.

JEL Classification / Clasificación JEL: Q32, J11, Q53, O57.

1. Introduction

Carbon emissions and environmental sustainability are deeply interconnected, especially amid growing global concerns. Industrialization, demographic changes, and rising energy consumption have intensified greenhouse gas emissions. Economic growth and population expansion are key contributors - particularly in E-7 countries (Brazil, Indonesia, China, Mexico, India, Türkiye, and Russia), where emissions have significantly increased (Zhao et al., 2021). These nations now produce nearly half of global emissions, with Russia, China, and Türkiye surpassing the global per capita average. This highlights the urgent need for targeted policies and sustainable development strategies to combat climate change.

Mineral depletion refers to the gradual loss of soil minerals (Akram et al., 2024). Rapid population growth and industrialization have escalated mineral demand, raising serious concerns about resource exhaustion (Xiong et al., 2023). This depletion affects energy use, energy production, CO_2 concentration, and the long-term sustainability of natural resources (Azam et al., 2023; Sun and Yao, 2023). It also contributes to environmental issues such as soil erosion, biodiversity loss, and air and water pollution (Lu and Wang, 2023). Moreover, mineral depletion can increase natural resource rents, which in turn may worsen ecological damage, as CO_2 emissions tend to rise with higher resource rents (Wang and Lei, 2023). Overall, mineral resource depletion poses a global environmental challenge with far-reaching consequences (He et al., 2024).

Existing literature has extensively examined the drivers of carbon emissions, often through the lens of the Environmental Kuznets Curve (Grossman and Krueger, 1994). Commonly identified factors include economic development (Kong, 2021; Iheonu et al., 2021; Mongo et al., 2021), population growth (Gonzalez-Sanchez and Martin-Ortega, 2020; Chien et al. 2022; Sterpu et al., 2018), and urbanization (Liu et al., 2017; Gudipudi et al., 2016; Zhao and Xi, 2022; Chen et al., 2023). However, mineral depletion, defined by the World Bank as the ratio of remaining resource stock to the period of exhaustion, has not been sufficiently explored in this context, despite its importance for environmental sustainability. Examples of studies that investigate the role of resource depletion and environmental degradation in different dimensions include Hussain et al. (2020), Eufrasio et al. (2022), Sibt-e-Ali et al. (2023), and Mohammed and Pata (2024). However, these studies have not investigated how mineral depletion, population density, energy productivity, and economic growth affect the challenges posed by greenhouse gas emissions. This issue is becoming increasingly critical in E-7 countries.

Accordingly, this study seeks to make an additional contribution to the literature by investigating the relationship between CO_2 emissions and mineral depletion. The research is driven by the growing relevance of the CO_2–mineral depletion nexus in E-7 countries, where mineral depletion may be shown to exacerbate ecological degradation, including its contribution to rising CO_2 emissions. In this context, the study investigates carbon emissions in E-7 countries from 1992 to 2021, focusing on the effects of mineral depletion and controlled by effects of population density, economic growth, and energy productivity. To analyze relationships, the study employs Driscoll-Kraay, DOLS, FMOLS, as well as MMQR methods to capture quantile-specific effects. Results indicate that mineral depletion, economic growth, and population density consistently increase carbon emissions across all quantiles. In contrast, energy productivity reduces emissions at every quantile level. These findings emphasize the importance of environmental awareness campaigns in E-7 countries and support policy recommendations for cleaner production, renewable energy adoption, and sustainable mining practices.

2. Literature review

The rise in carbon emissions poses a significant threat to climate stability, environmental quality, and long-term sustainability. Numerous studies have examined the causes of carbon emissions and their climate impacts. Given the importance of mineral depletion for sustainable development, its relationship with carbon emissions deserves closer attention. However, the literature shows a clear gap: while economic development, energy productivity, and population density are widely recognized as key drivers of carbon emissions, the direct effect of mineral depletion remains understudied.

Research on economic development and carbon emissions frequently draws on the Environmental Kuznets Curve (EKC), which proposes an inverted U-shaped relationship between pollution and income. This hypothesis has been extensively debated. Early contributions include Grossman and Krueger (1994), Shafik (1994), and Stern et al. (1996), who linked economic growth to environmental outcomes. Subsequent studies by Cole et al. (1997), Moomaw and Unruh (1997), Panayotou (1997), Agras and Chapman (1999), Millimet et al. (2003), Taguchi (2012), Aung et al. (2017), and Shahbaz and Sinha (2019) further expanded EKC analysis. More recent work, such as Duong (2022), Hannesson (2022), Acaroğlu et al. (2023), and Pata and Hizarci (2023), applies the EKC framework to various regions, including Asia- Pacific and countries like Türkiye, Germany, Sweden, and Switzerland.

Studies directly examining the economic growth–carbon emissions nexus are also extensive. Heil and Selden (2001) projected global emissions trends, suggesting a common pattern across countries. Azomahou et al. (2006) used a nonparametric panel approach for 100 countries and found a strong link between GDP and emissions. Ayeche et al. (2016) applied the General Linear Model to 40 European countries, identifying bidirectional causality. Nam et al. (2020) explored nonlinearities across income groups, while Zou and Zhang (2020) documented dynamic and spatial spillover effects in China, confirming the positive influence of economic growth on emissions.

Additional studies investigate long-run relationships between economic growth and environmental indicators. Gövdeli (2020) identified long-term cointegration and bidirectional causality in 14 Asia-Pacific countries. Onofrei et al. (2022) reported that a 1% increase in economic growth leads to a 0.072% rise in emissions in EU countries. Tleppayev and Zeinolla (2023) emphasized the importance of emissions in growth–environment relationship in Kazakhstan.

Population density, shaped by urbanization and city expansion, has long been considered a major driver of carbon emissions. Some studies focus directly on urbanization's impact on emissions (Poumanyvong and Kaneko, 2010; Martīnez-Zarzoso and Maruotti, 2011; Sharif Hossain, 2011; Zhu et al., 2012; Wan et al., 2014; Gately et al., 2015), while others examine its influence on energy consumption (Jones, 1991; Lariviēre and Lafrance, 1999; Steemers, 2003; Mindali et al., 2004; Ewing and Rong, 2008; Liu, 2009; Feng et al., 2011; O'Neill et al., 2012). Some studies link urbanization to greenhouse gas emissions (Du and Xia, 2018; Dodman, 2009; Kennedy, 2009; Dhakal, 2010; Hoornweg et al., 2011; Lee and Lee, 2014; Dominguez, 2023), emphasizing the role of urban spillover effects on environmental degradation. Empirical findings on population density are mixed but informative. Fragkias et al. (2013) showed that larger U.S. cities emit more carbon. Baur et al. (2014) found that density alone does not explain emission differences across European cities. Gudipudi et al. (2016) reported that doubling population density improves CO_2 efficiency by 42%. Liu et al. (2017) observed that density's elasticity shifts from positive to negative as welfare increases in China. Ribeiro et al. (2019) concluded that both population size and density affect emissions, with size having a stronger influence. Other studies confirm these relationships. Zarco-Periñán et al. (2021) found a positive link between density and building-related emissions in Spain. Zhao and Xi (2022) identified nonlinear effects of population size and industrial structure in Chinese cities, showing that emissions rise in early stages of urban growth. Rahman et al. (2020) reported unidirectional causality from density to emissions in South Asia. Muhammad et al. (2020) highlighted the joint role of density and energy consumption in Pakistan. Ma et al. (2021) identified a U-shaped relationship between population size and emissions in China's Yangtze River Delta, along with a negative sublinear link between density and emissions. Overall, while some studies find negative effects, most confirm a significant positive relationship between population density and carbon emissions.

The literature also examines the role of energy productivity. Oyebanji et al. (2023) showed that higher energy productivity reduces emissions in Denmark. Cui et al. (2024) found similar results for BRICS countries using the Augmented

Mean Group (AMG), FMOLS, DOLS, and CSARDL methods. Cheng et al. (2021) demonstrated that rising energy productivity lowers emissions in China using advanced cointegration techniques.

Despite extensive research on natural resource depletion, few studies focus specifically on mineral depletion's direct link to carbon emissions. Hussain et al. (2020) found that natural resource depletion increases emissions. Khan et al. (2021) identified bidirectional causality between natural resources and environmental quality in the U.S. Eufrasio et al. (2022) examined the environmental impacts of mineral depletion, while Norgate and Haque (2010), Azadi et al. (2020), Hund et al. (2020), and Mohammed and Pata (2024) explored mineral use, processing, and climate implications. Moreover, several studies address structural aspects of mineral depletion. Tilton (2002) examined its potential negative effects, while Thomas (2007) linked mineral depletion to food systems. Tilton (2009) discussed its implications for sustainable mining. Bardi et al. (2016) warned of future challenges, and Ponomarenko et al. (2021) highlighted risks for mining companies and social welfare.

Overall, the literature indicates that mineral and energy resource depletion pose significant risks for sustainable development. However, the direct relationship between mineral depletion and carbon emissions remains insufficiently explored. This gap underscores the need for further investigation. Accordingly, this study examines whether mineral depletion, population density, energy productivity, and economic development contribute to environmental deterioration in E-7 countries. The next section presents empirical analysis and findings.

3. Data and methodology

3.1. Data

This study examines the effects of mineral depletion, population density, energy productivity, and economic development on CO_2 emissions in the E7 countries over the period 1992–2021. Variable CO_2 is dependent variable and denotes CO_2 emissions per capita measured in metric tons. Explanatory variables are: MD – mineral depletion, GDP - GDP per capita, expressed in constant 2015 US dollars, used as the proxy for economic development; ED - energy productivity measured in GDP per unit of energy use (PPP $ per kilogram of oil equivalent), and PD – population density. All variables were obtained from the World Development Indicators database of the World Bank.

Detailed descriptive statistics for the variables are presented in Table 1. Generally, the mean values indicate the average levels of each variable, with CO_2 at 4.076, MD at 0.324, PD at 119.491, EP at 8.104, and GDP at 5963.761. The degree of variability around these means is reflected in the standard errors: 3.348 for CO_2, 0.3361 for MD, 123.077 for PD, 3.776 for EP, and 3433.276 for GDP. The minimum and maximum values reported in Table 1 represent the lowest and highest observations for each variable over the sample period. The Jarque–Bera

(JB) normality test is statistically significant at the 0.05 level for CO_2, MD, PD, EP, and GDP, indicating that all variables deviate significantly from a normal distribution.

Table 1. Overview statistics of variables

Variables	CO_2	MD	PD	GDP	EP
Observations	210	210	210	210	210
Mean	4.076	0.324	119.491	5963.761	8.104
St. Errors	3.348	0.336	123.077	3433.276	3.776
Lowest	0.690	0.004	8.716	549.235	1.268
Maximum	13.672	1.782	473.418	13670.94	16.945
J-B Statistics	32.87	69.99	45.78	151.03	39.75
P-value	0.000	0.000	0.000	0.000	0.000

Source: Own elaboration based on WDI data.

3.2. Pre-estimation tests

To assess the statistical adequacy of the variables, a series of diagnostic tests is conducted. First, the variance inflation factor (VIF) test is employed to detect potential multicollinearity, which indicates whether linear relationships exist among the regressors. Next, cross-sectional dependence in the panel dataset is examined using the Pesaran (2004) CD test. In addition, the Pesaran and Yamagata (2008) slope heterogeneity test is applied to evaluate whether the slope coefficients are homogeneous or heterogeneous across cross sections. If the Pesaran (2004) CD test confirms the presence of cross-sectional dependence and the Pesaran and Yamagata (2008) delta test rejects the null hypothesis of slope homogeneity, then a second generation unit root test is required. For this purpose, the study utilizes the Pesaran (2007) CADF test, whose null hypothesis states that the series contains a unit root. The CADF test is defined as follows:

$$\Delta y_{it} = \alpha_i + g_i T + b_i y_{i,t-1} + \sum_{j=1}^{p} \delta_{ij} \Delta y_{i,t-j} + \varepsilon_{it} \quad (1)$$

In the CADF specification, T denotes the time trend, b_i represents the coefficient on the lagged dependent variable, and ε_{it} is the error term.

Finally, the panel cointegration test is applied. The paper uses Westerlund's (2008) test for data I (1). This test provides four statistics: G_t, G_α, P_t and P_α. G_t and G_α analyze the cointegration relationship for at least one cross-sectional unit, while P_t and $P_\alpha$evaluate the cointegration relationship for the panel as a whole. If the null hypothesis of no cointegration between variables is rejected, then estimators for cointegration variables are applied.

3.3. Estimation methodology

The model created for the investigation is as follows (Eq. 2):

$$CO2_{it} = \alpha_i + \beta_1 MD_{it} + \beta_2 PD_{it} + \beta_3 GDP_{it} + \beta_4 EP_{it} + \varepsilon_{it} \tag{2}$$

where the acronyms stand for CO_2 emissions (CO_{2it}), mineral depletion (MD_{it}), population density (PD_{it}), GDP per capita (GDP_{it}), energy productivity (EP_{it}) and error term (ε_{it}).

The main empirical technique employed in this study is the Method of Moments Quantile Regression (MMQR). This approach offers several advantages over standard panel quantile regression and linear estimators such as FMOLS and DOLS (Alavijeh et al., 2024). MMQR provides more reliable and consistent estimates in the presence of endogeneity and multicollinearity (Afshan et al., 2024). It is particularly suitable when the panel data model includes endogenous explanatory variables and individual-specific effects (Ike et al., 2020). A key strength of the MMQR methodology is its ability to capture how regressors influence the entire conditional distribution of the dependent variable, while also allowing the use of robust techniques for estimating conditional means (Esen et al., 2024). This method is also effective in addressing potential outliers that may distort the overall distribution of the data (Hieu and Mai, 2023). By incorporating fixed effects to account for distributional heterogeneity across different quantiles of the dependent variable, MMQR overcomes limitations associated with traditional quantile regression (Machado and Santos-Silva, 2019; Ike et al., 2020; Wolde-Rufael and Mulat-Weldemeskel, 2022). MMQR estimates coefficients by linking the explanatory variables to various quantiles of the dependent variable (Zheng et al., 2024). It effectively addresses issues related to endogeneity, time effects, individual heterogeneity, and location-specific influences (Ghosh et al., 2023). The method is particularly appropriate when the panel exhibits individual-specific effects and contains endogenous regressors. Moreover, MMQR produces robust estimates even under nonlinear model structures (An et al., 2021). It facilitates the estimation of complex models and enables the derivation of non-overlapping regression estimates (Machado and Santos Silva, 2019).

The conditional quantile model can be expressed as follows, based on the estimation of the location and scale parameters. Given what the conditional quartile indicates, $Q_\tau(\tau|Y_{it})$ and

$$CO2_{it} = \alpha_i + \ddot{Y}_{it}\mu + \left(\dot{\omega}_i + \dot{P}'_{it}\psi\right)\varepsilon_{it} \tag{3}$$

where α, μ, $\dot{\omega}$, and ψ are the values of the parameters that need to be estimated. The formula (3) also includes the probability t that $(\dot{\omega}_i + 'P_{it}\psi) >$ 0 and equal to 1. The individual fixed effect is represented by the discrete "i".

The converted element " P," denoted as d, displays the selected elements of Y's k-vector as follows:

$$P_d = P_d(Y), \qquad d = 1, 2, \ldots, n \tag{4}$$

As $\ddot{Y}_{it}$ exhibits a uniform and independent distribution for every "d," it remains independent of time (t). To satisfy the moment's requirements of MMQR, ε_{it} must be appropriately orthogonally normalized to Y_{it} and re-distributed across the person's "d" at time (t). After changing the equation, the following equation is produced.

$$Q_\tau(\tau \mid Y_{it}) = (\alpha_i + \dot{\omega}_i q(\tau)) + \ddot{Y}_{it}\mu + \dot{P}'_{it}\psi q \tag{5}$$

The quantile distribution of the dependent variable $CO2_{it}$ is defined as $Q_\tau(\tau|Y_{it})$ while the vector parameters of the variables that are independent, namely MD, PD, EP and GDP, are shown as $\ddot{Y}_{it}$.The function of q(τ) is represented by the sample quantile, like (τ – *th*). The following may be used to derive the optimization problem:

$$\min_q = \sum_i \sum_t \rho_\tau \left(R_{it} - (\hat{\omega}_i + \hat{P}'_{it}\psi)q \right) \tag{6}$$

In the equation, the function of verification is denoted as:

$$\rho_\tau(R) = (\tau - 1)\tilde{R}\, I\{\tilde{R} \leq 0\} + \tau \tilde{R}\, I\{\tilde{R} > 0\} \tag{7}$$

To enhance the credibility of the empirical findings, the robustness of the MMQR results is assessed using DOLS, FMOLS, and the Driscoll–Kraay estimator. The FMOLS estimator effectively addresses endogeneity-related deviations and the resulting correlation between the regressors and the error term, while the DOLS estimator corrects for biases arising from the inherent correlation between the explanatory variables and the error term. These advantages justify their application in the present study (Ozturk et al., 2022). In addition, the Driscoll–Kraay estimator, which is known to produce strong and reliable empirical results (Joshi et al., 2021), is also employed to further validate the robustness of the findings.

4. Results and discussion

4.1. Diagnostic analysis

This section presents the empirical results of the analysis and provides a critical assessment of the findings. Following the descriptive statistics reported in Table 2, potential multicollinearity is evaluated using the VIF test. Table 2 displays the VIF results, indicating that the VIF values for the explanatory variables MD, PD, EP, and GDP are all below the threshold of five. Moreover, the tolerance values exceed 0.10, confirming the absence of multicollinearity and suggesting that the explanatory variables are not excessively dependent on one another.

Table 2. Findings on the VIF test for multicollinearity

Variables	VIF	1/VIF
MD	1.06	0.944
EP	1.28	0.780
PD	1.96	0.510
GDP	2.27	0.441
Mean VIF	1.64	-

Source: Own elaboration.

Addressing cross-sectional dependency (CSD) is a critical step in panel data analysis, as failure to do so may result in inaccurate inference, biased and inefficient estimates, and ultimately misleading conclusions (Rodriguez-Caballero, 2022; Ahakwa et al., 2023). Both heterogeneous slope coefficients and CSD are common challenges in panel datasets (Xie and Jamaani, 2022). In this study, the Pesaran (2004) CD test is employed to detect the presence of CSD. In addition, the Pesaran and Yamagata (2008) slope heterogeneity test is applied to examine whether the slope coefficients differ across cross-sectional units.

Table 3 reports the results of the Pesaran (2004) CD and Pesaran and Yamagata (2008) tests. The Pesaran (2004) CD test yields statistically significant results for all variables, indicating the presence of cross-sectional dependence in the model. Moreover, the slope heterogeneity test confirms that the slope coefficients are heterogeneous across units, suggesting that the relationships among the variables vary across countries.

TABLE 3. FINDINGS ON THE PESARAN (2004) CD TEST AND SLOPE HETEROGENEITY TEST (PESARAN AND YAMAGATA, 2008)

	Variables	CD-Test	p-value
CD test (Pesaran, 2004)	CO_2	12.45	0.000
	MD	14.47	0.000
	PD	12.28	0.000
	EP	23.50	0.000
	Test	Value	P-value
Slope heterogeneity test (Pesaran and Yamagata, 2008)	$\hat{\Delta}$	11.657	0.000
	$\hat{\Delta}_{adjusted}$	13.033	0.000

Source: Own elaboration.

In the next step, unit root testing is conducted after establishing the presence of slope heterogeneity and cross-sectional dependence. To assess the stationarity properties of the variables, this study employs a second generation unit root test, which is appropriate when cross-sectional dependence is detected in the panel. Specifically, the Pesaran CADF (2007) test is utilized for this purpose. Table 4 reports the results of the CADF test. The findings indicate that all variables in the model become stationary after first differencing.

TABLE 4. RESULTS ON PESARAN CADF (2007) TEST

Variables	Level	First Difference
CO_2	-2.670	-3.568***
MD	-2.088	-3.554***
PD	-2.547	-4.237***
GDP	-1.340	-3.828***
EP	-1.291	-4.440***

*** denotes significance at 1%.
Source: Own elaboration.

Before examining the long-run relationship between CO_2 emissions and the exogenous variables (PD, GDP, EP, and MD), it is first necessary to determine whether the system is cointegrated. To obtain reliable inference, the analysis is extended by employing the second generation Westerlund (2008) cointegration test, which is appropriate in the presence of cross-sectional dependence. First generation panel cointegration tests may yield unreliable results under such conditions. The Westerlund test results, presented in Table 5, indicate the existence of a long-term relationship among the variables. Accordingly, we conclude that CO_2 emissions, MD, PD, EP, and GDP exhibit a long-run cointegrating relationship in the E7 countries.

Table 5. Westerlund (2008) bootstrap cointegration test results

Statistics	Value	Z-value	P-value
Gt	-3.949	-5.068	0.000
Ga	-18.746	-3.299	0.001
Pt	-10.882	-5.213	0.000
Pa	-16.926	-3.912	0.000

Source: Own elaboration.

4.2. Estimation results and discussion

Table 6 presents the results of the FMOLS, DOLS, and Driscoll–Kraay estimators prior to the MMQR analysis. The consistency of the coefficients across these three methods (in terms of magnitude, sign, and statistical significance) confirms the robustness and reliability of the estimates. Across all techniques, the relationship between MD and CO_2 is positive. While the DOLS and Driscoll–Kraay estimates are statistically significant, the FMOLS coefficient is positive but statistically insignificant. These findings suggest that environmental degradation increases with mineral depletion in the E-7 countries.

Similarly, all three estimation methods indicate a positive association between PD and CO_2 emissions. Although the DOLS estimate is statistically insignificant, the FMOLS and Driscoll–Kraay results show a statistically significant relationship, reinforcing the conclusion that population density contributes to higher CO_2 emissions. The results for GDP also reveal a positive and statistically significant relationship with CO_2 emissions across all three estimators, indicating that economic growth is associated with increased carbon emissions in the E-7 economies. Finally, the FMOLS, DOLS, and Driscoll–Kraay findings consistently show that higher energy productivity reduces CO_2 emissions. The negative and statistically significant coefficients across all three methods confirm that improvements in energy productivity contribute to environmental sustainability in the E-7 countries.

Table 6. DOLS, FMOLS, and Driscoll-Kraay estimation results

	DOLS		FMOLS		Driscoll-Kraay	
Variables	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
MD	0.982	0.000	0.425	0.067	0.381	0.010
PD	0.012	0.099	0.021	0.004	0.010	0.000
GDP	0.0003	0.000	0.0002	0.000	0.0005	0.000
EP	-0.058	0.002	-0.038	0.020	-0.165	0.000

Source: Own elaboration.

Table 7 presents MMQR results showing a positive relationship between mineral depletion and CO_2 emissions across all quantiles. It suggests that results for every quantile were statistically significant. In the E-7 nations, greater environmental harm is also a result of rising mineral depletion. Population density also positively affects CO_2 emissions. Across all quantiles analyzed, statistically significant results were achieved. Thus, it has been shown that another factor influencing carbon emissions in E-7 nations is population density. There was a positive relationship between the GDP and CO_2 variables at all quantile levels, according to the results. Additionally, the results are statistically significant. Lastly, a negative relationship is seen at all quantile levels when analyzing the direction of the link between the energy productivity and CO_2. Additionally, each of these results is statistically significant. Carbon emissions fall in E-7 nations as energy productivity rises.

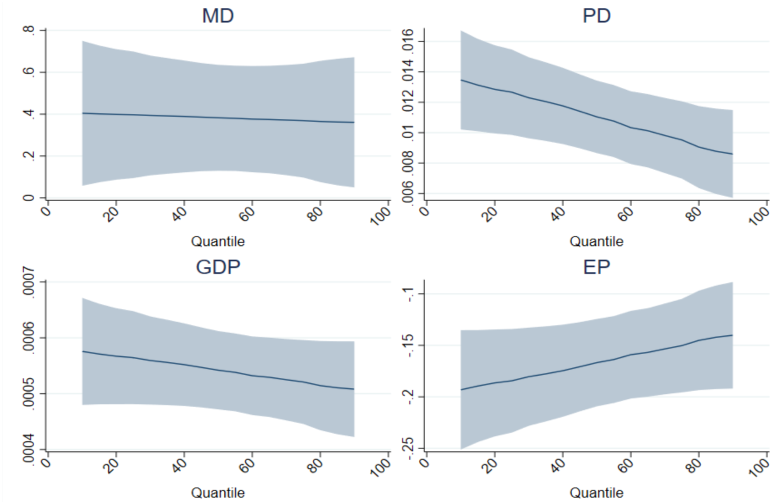
Table 7. Estimation results using the MMQR method

	Variables			
	MD	PD	GDP	EP
Location	0.381***	0.010***	0.0005***	-0.165***
Scale	-0.015	-0.001**	-0.00002	0.018
Quantile				
0.10	0.404**	0.013***	0.0005***	-0.193***
0.20	0.398**	0.012***	0.0005***	-0.186***
0.30	0.393***	0.012***	0.0005***	-0.180***
0.40	0.389***	0.011***	0.0005***	-0.174***
0.50	0.382***	0.011***	0.0005***	-0.166***
0.60	0.376***	0.010***	0.0005***	-0.159***
0.70	0.371***	0.009***	0.0005***	-0.153***
0.80	0.365**	0.009***	0.0005***	-0.145***
0.90	0.361**	0.008***	0.0005***	-0.140***

Note: **, and *** denote significance at 5%, and 1%, respectively.
Source: Own elaboration.

Figure 1 provides a graphical illustration of these MMQR results and visually confirms the patterns observed in the empirical analysis.

Figure 1. MMQR plot of calculated coefficients



Source: Own elaboration based on data.

5. Conclusions and policy recommendations

Environmental deterioration constitutes a significant challenge for the E-7 nations, which collectively accounted for 49.3% of global CO_2 emissions in 2020. Structural global trends, including population growth, rising GDP per capita, and increasing mineral depletion, pose substantial risks to environmental sustainability. This study investigates the relationship between CO_2 emissions, population density, economic development, energy productivity, and mineral depletion in seven E-7 countries from 1992 to 2021, with a key contribution being its explicit focus on the environmental implications of mineral depletion.

To ensure the robustness of the empirical findings, the analysis incorporates a comprehensive set of preliminary tests, including tests for cross-sectional dependence, slope heterogeneity, unit roots, and cointegration. The FMOLS, DOLS, and Driscoll–Kraay estimators are employed to examine average effects across the panel. The results indicate that mineral depletion, population density, and economic growth significantly increase CO_2 emissions, whereas improvements in energy productivity contribute to reducing carbon emissions.

These findings carry important implications for E-7 policymakers. Implementing rules pertaining to mineral rents should be the first priority when it comes to mineral depletion. Regulations should be put in place to guarantee that environmental taxes rise in tandem with the increase in mineral rents. Green mining requirements should be made mandatory for E-7 nations. Given that the depletion of minerals also contributes to the depletion of natural resources and, therefore, the deterioration of the environment, efforts should be undertaken to assist the E-7 nations in making the shift to a low-carbon economy. In these nations, investments in low-carbon mining should be supported together with clean energy sources. Beyond the connection between mineral depletion and carbon emissions, it can be concluded from other research results that environmental sustainability in these nations depends on the promotion of eco-friendly technology. In this regard, E-7 nations should prioritize green development strategies and establish stringent regulations to reduce carbon emissions in highly polluting sectors. Targeted policies are needed to facilitate the transition of these industries toward a low-carbon economy. In addition, migration from densely populated areas to less populated regions should be encouraged through population planning policies aligned with environmental sustainability goals. Creating green employment opportunities in sparsely populated areas can support this transition and help alleviate environmental pressure in overcrowded cities. Accordingly, E-7 countries should adopt policies aimed at expanding green jobs. Furthermore, energy productivity should be a central consideration in the design of environmental sustainability policies. Public awareness of energy-efficient products must be enhanced, alongside increased investment in energy productivity. Promoting energy-efficient transportation systems and establishing clear standards for energy-efficient housing regulations are also essential steps toward achieving long-term environmental sustainability.

Future research could broaden the analytical scope by incorporating indicators of economic globalization, examining trade flows among E-7 nations, and extending the analysis to other greenhouse gases such as methane and nitrous oxide. Sector-specific investigations, particularly in transport, industry, and agriculture, would also provide more targeted insights for designing effective emission-reduction policies. Overall, the findings underscore the need for E-7 countries to adopt comprehensive strategies that promote efficient mineral use and sustainable energy systems, ensuring that economic development is aligned with long-term environmental objectives.

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